This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

TRANSPORTATION
LIBRARY
TS
2025
.F55

A 794,209

The Worshipful Company of Coach and Coach-
Harness Makers' First Prize Essay.

DRAUGHT.

BY

WILLIAM PHILIPSON

NEWCASTLE-UPON-TYNE.

1817
ARTES VERITAS SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN

TRANSPORTATION
LIBRARY

TS
20[illegible]
.P66

tion

The Worshipful Company of Coach and Coach Harness Makers' First Prize Essay.

DRAUGHT.

BY

WILLIAM PHILIPSON,

NEWCASTLE-UPON-TYNE,

Associate of Science, Durham University; Graduate of the Institute of Mechanical Engineers, and of the Institute of British Carriage Manufacturers; Certificated Teacher for the City and Guilds of London Institute, by full Honours Certificate in the Examination on Coachbuilding.

TRANSPORTATION LIBRARY
UNIVERSITY OF MICHIGAN

LONDON:
JOHN KEMP AND CO., 46, CANNON STREET, E.C.

1885.

JOHN KEMP AND CO., PRINTERS,
ASPLEY GUISE, BEDS.

Heaven
11-12-29

PREFACE.

THOUGH much has been written about the draught of a carriage it is curious how little there is from a coachbuilder's point of view. The writings of Cummings, Edgeworth, and others, at the end of the last century and the beginning of this, had for their object the improvement of roads more than the improvement of carriages. They wanted carriages to act as road rollers, but happily Macadam came, and they gained their object in another way. The experiments of Morin later on in the century were nearer the mark, as they had for their object the improvement of gun carriages, and they are very valuable as far as they go. The remaining writers, such as Youatt, Dwyer, and Brown, deal more with draught from a horse's point of view.

The Worshipful Company of Coachmakers no doubt saw this want, and to it this Essay owes its origin. The writer feels the prominence that is thus given to his Essay, and though he was obliged to contract his remarks to twelve sheets of foolscap, he trusts it may give the reader a fair idea of what the draught of a carriage depends on. All the mathematical parts have been placed in foot-notes, so as to suit the general reader, in accordance with the wish expressed in the Judges' report.

For help in reading over and correcting proofs of Essay the writer is greatly indebted to Mr. G. A. Thrupp (Master of the Coach Makers' Company for the past year), Mr. G. N. Hooper (President of the Institute of British Carriage Manufacturers), and Mr. Herbert Mulliner, of Leamington; also to Mr. A. S. Herschel, M.A., F.R.S., Professor of Physics, Durham University, and to his College friend, Mr. J. Hawthorn, A.Sc., who also kindly helped him in making some of the experiments.

NEWCASTLE-UPON-TYNE,
June, 1885.

HEADINGS OF ESSAY.

CHIEFLY AS SUGGESTED BY THE COACH MAKERS' COMPANY.

Page.

Causes of Draught—1—The Resistance Offered to Rolling of the Tyre on the Road - - 5-7
2—The Friction of the Metal Box round the Axle Arm - - 7-8
3—The Force of Gravity - - - 8
4—The Speed at which the Carriage is Driven - - - - - - 8-9
Angle of Trace - - - - - - - - - - - 10-11
Best Height of Wheels - - - - - - - - 11-13
Coupling of a Carriage - - - - - - - - 13
Track of a Carriage - - - - - - - - - 13
Dish of Wheels or Pitch of Axle Arm - - - - - 13
Best Form of Tyre - - - - - - - - - 13-14
Position of Body on Wheels - - - - - - 14
Best Point of Draught - - - - - - - - 15-16
Height of Point of Draught - - - - - - 16-17
Comparison between Two and Four-Wheeled Carriages - 17
Best Method of Working Two and Four-Wheeled Carriages 17-18
Comfort—Springs - - - - - - - - 18-19
Lancewood Shafts - - - - - - 19
India-Rubber Tyres and India-Rubber Axle Collars 19
Springs in Traces - - - - - - 19-20
Pulling or Sway Bars - - - - - - - 20
Appendix, with Results of Experiments - - - - i.-v.

LIST OF AUTHORITIES REFERRED TO FOR INFORMATION.

Adam's "Pleasure Carriages."
Berdmore's (Nimshivich) "Scratch Team of Essays."
Bourn on "Wheel Carriages, 1763."
Brown, Capt. C. Orde, 14th Brigade, R.A., "Short Notes on Field Batteries, Part I."
Cummings on "Wheel Carriages."
Dwyer, Major, on "Draught and Harness."
Edgeworth on "Wheels and Roads."
Emmersen's "Mechanics."
Felton on "Carriages."
Hooper, in several of the "International Exhibition Reports."
Morin's French work on "Draught," also his "Mechanics."
Moseley, in his "Mechanical Principles of Engineering."
Partington on "Wheels and Wheelmaking."
Philipson on "Harness."
Rankine, Professor, on "Applied Mechanics."
Richardson, in pamphlet on "Carriages."
Robertson's (Glasgow) Articles on "Draught," in *Saddlers' Gazette.*
Royal Agricultural Society's Report on "Bedford Experiments, 1878," and *Engineer* on same.
Stratton's, Articles on "Draught;" in *New York Journal.*
Twisden's "Practical Mechanics."
Thrupp, in his "History of Art of Coachbuilding," and pamphlet on "Weight of Carriages."
Youatt's Essay on "Draught," in "Book of Horse."
Young's (Dr.) Philosophy Lecture on "Carriage Wheels."

PRIZE ESSAY

ON

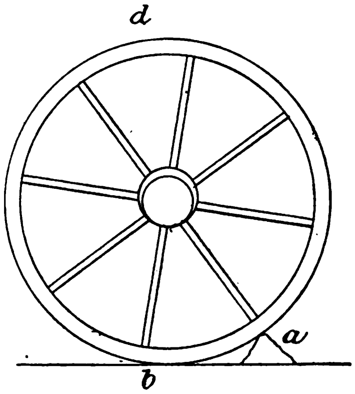
DRAUGHT.

THE draught of a carriage is mainly composed of the resistances offered to the motion of the wheels, which are caused by:—

1.—The resistance offered to the rolling of the tyre on the road.
2.—The friction of the metal box round the axle arm.
3.—The force of gravity.
4.—The speed at which the wheel is driven.

Resistance No. 1.—This resistance can be dealt with in two ways. First, by considering that the wheel is continually surmounting small obstacles, which, for a given road, have a certain average effect. Secondly, as the resistance offered by a plane surface to a cylinder rolling upon it.

From the investigation of the first method in the footnote[1], we



find that if we suppose *a b d* to represent a wheel in contact with an obstacle at a, and b the point of contact of the wheel with the road, that the power required at the axle to draw the wheel bears to the total weight with which it is pressed to the ground the same proportion as the length of the arc $b\ a$ bears to the radius of the wheel;

$$\text{Or,}\quad \frac{\text{power}}{\text{weight}} = \frac{\text{arc } b\ a}{\text{radius of wheel}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(\text{I.})$$

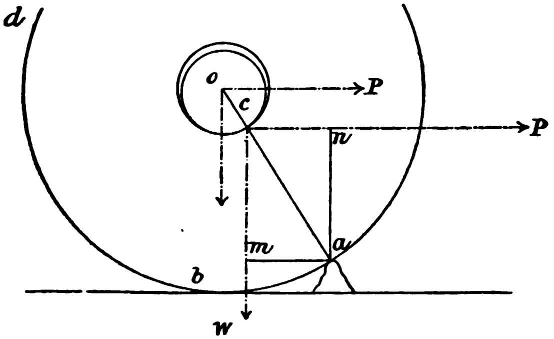
The second method was thoroughly investigated by Coulomb, who made a large number of experiments by rolling different cylinders on different plane surfaces, some of which are to be found in Morin's work (pages 7 to 28). After summarising them, he found that the power required at the axle to draw the wheel was directly proportional to the weight, and inversely proportional to the radius of the wheel. That is to say, a wheel of large diameter is easier to pull than one with a less diameter, the weight being the same in the two cases;

$$\text{Or,}\quad \frac{\text{power}}{\text{weight}} = \frac{\text{a constant}}{\text{radius of wheel}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(\text{II.})$$

It is obvious that the only resistance that a solid plane can offer to a cylinder rolling on it must arise from small roughnesses on its surface, or from the wheel being in a depression by reason of its compressing the surface that it rolls upon, as is the case with wheels on india-rubber. Therefore Coulomb's experiments are really an investigation of the resistance offered by obstacles in the path of the wheel; consequently, the two expressions for the draught of a wheel are the same, that is (I.) and (II.).

---

[1] *Resistance No.* 1.—To find the amount of the resistance at the tyre of the wheel, supposing it alone to act upon the wheel.



Let C be the point of contact between wheel and axle, and a and b the same points as above.

Combining them, we find the arc $b\,a$ is a constant for the same roads, whatever is the height of the wheel. To this constant we give the name of A. Its values for ordinary roads, as found by Morin, carriage moving at the rate of 1 metre (39·37in.) per second, are as follows :—

Kind of Road.	French values in Metres.	Equivalent value in Inches.
For hard and dry roads in good condition ...	·010	·4
,, pavement	·015	·6
,, ordinary muddy roads	·020	·8
,, very damp and muddy roads	·027	1·0
,, very soft roads and with narrow tyres sometimes as much as	·076	3·0

Resistance No. 2.—It is obvious that a certain portion of the horse's power is used in simply turning the wheels round the axles, and that if this friction did not exist the carriage would run easier. This resistance depends on the same laws as ordinary friction. From the foot-note[2] it is found that the power is very nearly proportional to the weight of the whole carriage, less the weight of the wheels. It is also proportional to a co-efficient of friction between axle and axle-box, which will vary according to the lubrication ; and to the ratio of the radius of the axle to the radius of the wheel ;

$$\text{or very nearly power} = \frac{\left\{\begin{array}{c}\text{weight}\\ \text{of carriage}\end{array} - \begin{array}{c}\text{weight}\\ \text{of wheels}\end{array}\right\} \times \begin{array}{c}\text{co-effict.}\\ \text{of friction}\end{array} \times \begin{array}{c}\text{radius}\\ \text{of axle}\end{array}}{\text{radius of wheel.}} \qquad \text{(III.)}$$

or the larger the axle the greater the resistance. This is easily explained by looking at the greater distance the axle has to travel in the larger axle-box in one revolution of the wheel than in the

---

W = weight of carriage.

P_1 = force required to pull carriage to overcome obstacle at tyre.

R = radius of wheel.

Draw $a\,m$ and $a\,n$ perpendicular to W and P_1 respectively.

The spoke of the wheel extending from the point of contact C, at which the tractive force P_1 and the weight W practically act, to the top of the obstacle at a, acts like a lever, the obstacle being the fulcrum.

Then by the principle of the lever $P_1 \times a\,n = W \times a\,m$

$$\text{Or,} \quad \frac{P_1}{W} = \frac{a\,m}{a\,n} = \frac{a\,m}{m\,c} = \tan.\ m\,c\,a = \tan.\ b\,o\,a$$

Since $b\,o\,a$ is a very small angle its tangent = its circular measure = $\dfrac{\text{arc } b\,a}{R}$

$$\text{Therefore} \quad P_1 = \frac{W \text{ arc } b\,a}{R} = \frac{W\,A}{R} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

smaller one, remembering that the axle only rubs on one part of the axle-box at one time.

No notice is taken of the length of the axle-arm, as the friction is independent of the amount of surface in contact. It must be understood that this surface is merely the small portion on the underside of the axle that presses against the box. It is advisable that the arm be not too short, as great weight spread over a small surface soon produces heat, causing the axle to stick ; nor must it be too long, as this increases the weight of the carriage, and looks unsightly ; but it should rather be too long than too short, as greater steadiness is imparted to the wheel.

Adding together the Resistances Nos. 1 and 2, found by Expressions (II.) and (III.), we obtain the expression for the whole draught of a carriage on a level road when the traction is horizontal.

$$\text{power} = \frac{\begin{matrix}\text{weight of}\\ \text{carriage}\end{matrix} \times \begin{matrix}\text{constant}\\ \text{A}\end{matrix}}{\text{radius of wheel}} + \frac{\left\{\begin{matrix}\text{weight of}\\ \text{carriage}\end{matrix} - \begin{matrix}\text{weight of}\\ \text{wheels}\end{matrix}\right\} \times \begin{matrix}\text{co-eff. of}\\ \text{friction}\end{matrix} \times \begin{matrix}\text{radius}\\ \text{of axle}\end{matrix}}{\text{radius of wheel}} \quad \ldots\ldots \text{(IV.)}$$

Resistance No. 3.—As soon as the road is inclined, the action of gravity affects the draught of a carriage very considerably, as it either retards it in going up-hill, or assists it in coming down. The effect increases very much on steep hills, and will make the rest of the expression for draught comparatively insignificant.[3] In such cases, the difference in draught caused by the varied height of the wheels in going up-hill is not generally observable.

Resistance No. 4.—The influence of speed on carriages is to increase the resistance or draught. Morin (page 160) found from

---

[2] *Resistance No. 2.*—To find the amount of friction at axle, let us suppose it to act alone on the wheel. Let P_2 = force pulling the wheel, required to just overcome friction at axle, R = radius of wheel, r = radius of axle, W = total weight of carriage, w = weight of wheel, $f = \mu$ Cos. ϕ ; μ and ϕ being the co-efficient and limiting angle of friction between axle and axle-box ; and S = resultant of P and W-w, which differs very little from W-w, and may be called the augmented carriage weight.

After one revolution of the wheel, the amount of work done at the surface of axle-box will be the friction $S\ f$ multiplied by the distance travelled or circumference of axle $2\ \pi\ r$. And this is balanced by the work done by the tractive force P_2, which travels over a distance equal to the circumference of wheel $2\ \pi\ R$, and the quantity of work done is equal to the quantity of work overcome, and the two quantities of work are equal.

Therefore, $P_2 \times 2\,\pi\,R = S\,f \times 2\,\pi\,r$

$$\text{or } P_2 = \frac{S\,f\,r}{R} = \frac{(W\text{-}w)\,f\,r}{R} \text{ very nearly } \ldots\ldots\ldots\ldots\ldots\ldots \text{(III.)}$$

$$\text{as } S = \sqrt{(W\text{-}w)^2 + P^2} \text{ which differs very little from } (W\text{-}w).$$

Combining equations (II.) & (III.) we have $P = P_1 + P_2 = \dfrac{W\,A}{R} + \dfrac{(W\text{-}w)\,f\,r}{R}$ .. (IV.)

his experiments that draught increases in such a manner that the increment of draught is in proportion to the increment of speed.[4] That is to say, that if it takes 10lbs. to pull a carriage at the rate of four miles per hour, and 11lbs. at five miles per hour, then it will take 12lbs. to pull it at six miles per hour.

---

[3] *Resistance No.* 3.—Suppose, now, that the road is inclined at an angle β to the horizon, and the traction at angle α to the road, so that the traction P makes an angle $(\alpha + \beta)$ with the horizon.

Then, as before, the force required parallel to the road to surmount an obstacle at the tyre. (P_1' say) = the pressure perpendicular to the road, multiplied by $\frac{A}{R}$

But $P_1' = P_1 \text{ Cos. } \alpha$, and the normal pressure = resolved part of weight perpendicular to the road, minus the resolved part of the traction perpendicular to the road = $W \text{ Cos. } \beta - P \text{ Sine } \alpha$

$$\therefore P_1 \text{ Cos. } \alpha = \frac{W \text{ Cos. } \beta - P \text{ Sine } \alpha}{R} \times A \text{ or } P_1 = \frac{(W \text{ Cos. } \beta - P \text{ Sine } \alpha) A}{R \text{ Cos. } \alpha} \text{(V.)}$$

In considering the retardation due to the friction at the axle, it must be remembered that the pressure is not the whole weight of the carriage without the wheels as before, but this quantity lessened by the vertically-resolved part of P (which acts at angle $\alpha + \beta$ to horizon), *i.e.*, vertical pressure $=(W\text{-}w) - P \text{ Sine } (\alpha + \beta)$, and the horizontal pressure $= P \text{ Cos. } (\alpha + \beta)$. Therefore force required to overcome friction at axle is

$$P_2 \text{ Cos. } \alpha = \frac{S f r}{R} = \sqrt{\left\{W\text{-}w - P \text{ Sine } (\alpha + \beta)\right\}^2 + \left\{P \text{ Cos. } (\alpha + \beta)\right\}^2} \times \frac{f r}{R}$$

and if we neglect the latter part of this equation, viz. $[P \text{ Cos. } (\alpha + \beta)]^2$, as it is very small compared with the other part of the equation, we obtain

$$P_2 = \left\{ (W\text{-}w) - P \text{ Sine } (\alpha + \beta) \right\} \times \frac{r f}{R \text{ Cos } \alpha} \ldots\ldots\ldots\ldots\ldots \text{(VI.)}$$

Besides these, the traction has to overcome the effect of gravity tending to pull the carriage down or up the slope, according as we suppose we are going up or down-hill. That is to say, it requires to exert an extra force equal to the resolved part of the total weight parallel to the slope of the road :—

$$\text{or,} \quad P_3 \text{ Cos. } \alpha = W \text{ Sine } \beta \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(VII.)}$$

Adding together the forces parallel to the road, required to move the carriage, which are given by Equations (V.), (VI.), and (VII.), we have :—

$$P = P_1 + P_2 + P_3 = A \times \left\{ \frac{W \text{ Cos. } \beta - P \text{ Sine } \alpha}{R \text{ Cos. } \alpha} \right\} + \left\{ \frac{W\text{-}w - P \text{ Sine } (\alpha + \beta)}{R \text{ Cos. } \alpha} \right\} \times r f + \frac{W \text{ Sine } \beta}{\text{Cos. } \alpha} \ldots\ldots \text{(VIII.)}$$

If the road be down-hill β will have a negative value, and it must be remembered, in applying the formula, that its sine is negative, while its cosine remains unchanged. If the direction of traction be parallel to the road, $\alpha = 0$ and the above equation becomes

$$P = \frac{A\, W \text{ Cos. } \beta + (W\text{-}w - P \text{ Sine } \beta)\, r f}{R} + W \text{ Sine } \beta \ldots\ldots \text{(IX.)}$$

If $\beta = 0$ the road is horizontal, and we have Equation (IV.) reproduced (Sine $\beta = 0$, Cos. $\beta = 1$). If the road be horizontal, and the trace inclined at angle α, Equation (VIII.) becomes

$$P = \frac{A\, (W - P \text{ Sine } \alpha)}{R \text{ Cos. } \alpha} + \frac{(W\text{-}w - P \text{ Sine } \alpha)\, r f}{R \text{ Cos. } \alpha} \ldots\ldots\ldots \text{(X.)}$$

If we neglect friction at axle, which is generally very small and differentiate with respect to α, we find that P is a minimum when tan. $\alpha = \frac{A}{R}$

Angle of Trace.—The angle at which the power is applied also affects the draught of a carriage, as if the traces are inclined upwards at a high angle the carriage is lifted off the ground as much as it is drawn along. Again, if they are sloping downwards,

---

From Equation (X.) neglecting friction

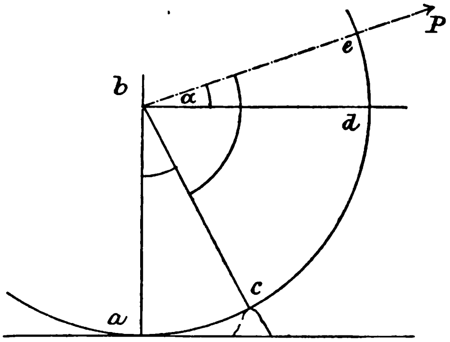
$$P = \frac{A\,(W - P \text{ Sine } a)}{R \text{ Cos. } a} = \frac{A\,W}{R \text{ Cos. } a + A \text{ Sine } a}$$

for a minimum $\frac{d\,P}{d\,a} = 0$ $\therefore$ its numerator $= 0$

$$\therefore\ A\,W(- R \text{ Sine } a + A \text{ Cos. } a) = 0$$

$$\therefore\ \frac{\text{Sine } a}{\text{Cos. } a} = \text{tan. } a = \frac{A}{R}$$

which is the circular measure of the angle at the centre of wheel intercepted between point of contact and top of obstacle, viz. : *a b c*. And we know that for small values of an angle its tangent = its circular measure. Therefore tan. a = tan. *abc*. Therefore a = *a b c*. Therefore the best inclination for trace to the road is at an angle = *a b c*, or, in other words, at right angles to *b e* the line joining the centre with top of obstacle.



We also find that this is the same angle that a carriage will just run down, for neglecting axle-friction and remembering that it is down-hill for value of β, from (IX.) we get $P = \frac{A\,W \text{ Cos. } \beta}{R} - W \text{ Sine } \beta = \frac{W\,(A \text{ Cos. } \beta - R \text{ Sine } \beta)}{R}$ and making $P = 0$ $A \text{ Cos. } \beta - R \text{ Sine } \beta = 0$ or $\frac{\text{Sine } \beta}{\text{Cos. } \beta} = \text{tan. } \beta = \frac{A}{R}$

Therefore the trace ought to be inclined at an angle that the carriage will just run down if left to itself, to get the least draught.

4*Resistance No.* 4.—The influence of speed on carriages is to increase the resistance or draught in such a manner that A, which we suppose to have the value ψ at the velocity V, has the value $\psi + \delta\,(V' - V)$ at the velocity V′, where δ is a constant, which for the pavement of Paris = ·009 for a carriage without springs, or ·002 for one with springs and ψ, or A, value as in table.

the carriage is pushed into the ground instead of being drawn along. It is found in practice that it is better to have the trace inclined upwards a little, so that the carriage may be lifted over an obstacle. In foot-note[3] the best inclination is worked out theoretically, and is found to be at right angles to the line joining the centre of wheel and top of obstacle, which is at the same inclination to the horizon as the carriage, if left to itself, would just begin to roll down, and is also the angle at centre of wheel, included by the arc *a b*, before referred to.

Best Height of Wheels.—Having become acquainted with the different resistances that act on a carriage, we are now in a position to proceed to decide the best height of wheels. We see, from the different expressions, that the resistances are reduced both at the tyre and the axle by increasing the height of the wheel, and, therefore, one would naturally say that the higher the wheel is the better. But if we put so large a wheel behind a horse that he is obliged to pull downwards, the draught will be increased rather than decreased. Again, the weight of a wheel increases very much with its height, as it must be made very much stronger, and this, in a light carriage, is an important matter. The cost, another important item, is also increased, as well as the difficulty to enter the carriage, and its liability to overturn. In four-wheelers, where a full lock is required, the height of front wheel is limited to the size of front arch.

It has been asserted that a low wheel is easier to draw up a hill than a high one, but this is clearly not the case, as the same mechanical advantage exists, unchanged, in favour of a high wheel, whatever slope the hill is. When the hill is pretty steep, the value of the resultant of the weight parallel to the road becomes so nearly equal to the weight that it puts into shade both the friction at tyre and axle, so that the difference in draught from high and low wheels is scarcely observable, though it still exists.

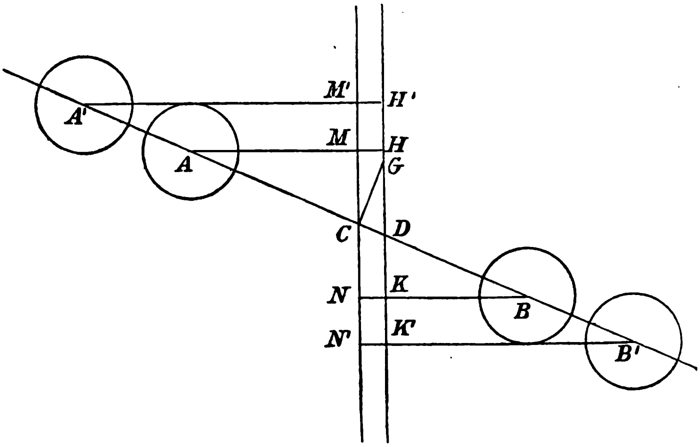
The general practice of making the front wheels of a four-wheeled carriage smaller than the hind ones is correct, inasmuch as in going up-hill the weight is thrown back, and therefore, on to the hind wheel, reducing the draught just when the horse has hardest work; and again, in going down-hill, the weight is thrown on the small wheel, thereby increasing the draught; but at the same time it would be well if the American style of having larger wheels, with little difference in height between front and back, were more generally adopted.

Coupling.—Seeing that draught is made up of the friction at the axle and the tyre of the wheel, and that neither of these resistances is in any way affected by the distance apart of the front and hind wheels, there can be no difference in draught between a long and short coupled carriage, always provided that the weights are equal, and they are similarly distributed on front and hind wheels in the two cases.

It may be mentioned that on inclines this relation practically still holds good (see footnote[5]), though the weights on the front and hind wheels are changed.

When comparing long and short coupled carriages, it must be remembered that the former are subject to greater strains, and greater tendency to vibrate and create noise, consequently they have to be built stronger, and therefore heavier.

It is better to bring the hind wheels of a brougham forward as far as the opening of the door will permit, for in this and other similar cases, the weight is simply placed more on the large wheels, and, of course, the draught is lessened. (See remarks at page 14.) On the brow of a hill a short coupled carriage has an advantage over the longer coupled one, but considering the small amount of draught that is saved by a few inches shorter coupling, and the short space of time (a few seconds) that the



---

[5] PROOF OF LONG AND SHORT COUPLING.

Suppose A B to represent a carriage on an incline, with A and B centres of the front and hind wheels, and that the coupling is lengthened so that A' and B' are the new centres. Let G be the centre of gravity, and G C a perpendicular line from G on A B. We are given that A' C : A C : : B' C : B C, and we want to see whether this proportion holds good on inclines, that is, whether the perpendiculars from the centres to the vertical line through the centre of gravity are still in the same proportion.

advantage lasts, it is evidently unwise to disfigure a carriage for so trifling a gain.

Track.—Whether the track of a carriage has anything to do with its draught is doubtful, but certainly it is not so easy for the horses when the track is very great, as the jerks of the pole or shafts against the sides of the horses will be great and objectionable. Again, it is advisable not to increase it more than say the "cart track," for reasons of strength, as the increased leverage of axle increases the sidelong and transverse shocks that are transmitted by the wheel to the pole, fore-carriage, &c.

Dish of Wheels.—The pitch of the arm of the axle (or the dish of wheels) does increase the draught to a certain amount owing to the increased friction at the axle collar, and in extreme cases the grinding of the tyre on the road, but to what extent it is difficult to say.

Tyre.—As to the best form of tyre, whether flat or half-round, on good hard roads, it is difficult to decide. It may be said of half-round tyres, that in meeting with stones they will, as a rule, push

---

We know that as soon as the carriage is on an incline, the weights on the front and hind wheels are changed, that is, if the distribution of weight on the wheels A and B, on the level, is in the proportion of A C to C B, the proportion becomes A D to D B, if D is the point of intersection between the vertical line from the centre of gravity, and the line A B joining the centre of wheels. That is, weight has been taken off the wheel A and put on the wheel B to the amount represented by the line C D, owing to the inclination of the road.

First suppose centre of gravity on line A B, say at C, then through this point draw vertical line M N, and perpendiculars to it from the centres of wheels A and B. Then on the incline the distribution of the weight on the wheels A and B is in the proportion of A M to B N. The distribution on A′ and B′ is in the proportion of A′ M′ to B′ N′. Now A′ C : A C : : B′ C : B C, but A′ C : A C : : A′ M′ : A M and B′ C : B C : : B′ N′: B N, by similar triangles, therefore A M : B N : : A′ M′ : B′ N′ that is the, distribution of weights on the short, coupled carriage, is the same as that on the long coupled one, when centre of gravity is on line joining centres of wheels, whatever is the inclination of the road.

Next suppose centre of gravity not on line A B, but at G, draw the vertical line H K through it, meeting A B at D, and the perpendiculars from A and B, at H and K respectively. Then on the incline the distribution of the weights on the wheels A and B is in the proportion of A H to B K, and on the wheels A′ and B′ in the proportion of A′ H′ to B′ K′. In the same way as before, viz. : by similar triangles it can be shewn

that A H : B K : : A D : D B
and that A′H′ : B′K′ : : A′D : D B′

Now if we could show that A D : D B : : A′ D : D, B′ we would be able to prove there was no difference between a long and short coupled carriage on inclines ; but working this proportion out we find it does vary to a small amount. The amount is less than C D, which is itself very small compared with A C and A′ C, and therefore we may say that there is no practical difference in the draught between a long and short coupled carriage, provided the distribution of the weight of the front and hind wheels is the same in the two cases, as well as the height of wheels, size of axles, and weight of carriage.

them aside, instead of passing over them, as a flat tyre does. Half-round tyres also look lighter, and do not carry mud, when slightly frozen, or sticky, but they simply cut through the layer of surface mud. On the other hand, flat tyres are not so liable to run in the tram lines, in towns where they are laid ; consequently the wheels are not strained so frequently as those hooped with half-round iron. Flat tyres also offer an advantage on soft roads as they do not sink so deeply into the ground.

Position of Body on Wheels.—The object to be sought in correctly placing a body on its wheels is to gain a minimum draught with maximum ease and durability. From Expression IV. the least possible draught is obtained by putting as much weight as possible on the higher wheels (supposing they are not equal), but by doing this it will be found that the other two requisites, ease and durability, will have to be sacrificed, for if the carriage is drawn pretty quickly along rough roads the small wheels will jump, and run unevenly. To prevent this, both front and hind wheels should be as large and as nearly of one size as possible, and the body should be placed so that the weight (of body, springs, axles, and load) is distributed on the front and hind wheels in the same proportion to their height (viz : the large wheels to have as much more of the load as they are larger than the small wheels). If this is carried out, it will be seen from the expression that the power required to pull the front and hind wheels will be equal, which is an advantage, as there will be an equal amount of work done by both, and they ought therefore to last the same time without repairs. The wheels being nearly equal, the weights will be nearly equal, and the liability to jump will be minimised ; but if it is necessary to have a very small wheel with a very large one, and its proportion of load is not enough to keep the carriage from jumping, at once break the rule and place a little more weight on the small wheels. In fixing the position of a body, it should always be kept as low as possible, as it prevents the tendency to oscillate or sway, which causes the draught to vary, and possibly exceed the power of the horse.

A single brougham is an example of a body fairly well positioned and planned for passengers, for if this is well made, the weight on the wheels when empty, is about equal, and when loaded, the load is equally divided (the driving-seat being as far behind the front axle as the other seat is in front of hind axle). The reverse is observed in a landau. This carriage, when empty, generally weighs 1cwt. to 2cwt. more in front than at hind end, and when loaded, most of the weight comes to the front. (The driving-seat and front seat are both near front axle, and the weight of the passengers on them is nearly all borne by this axle, while there is

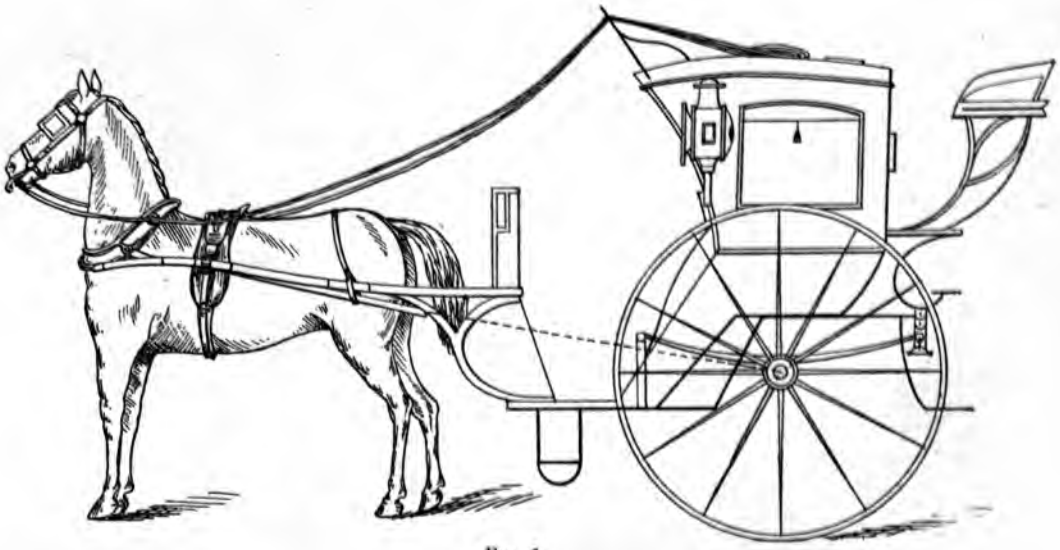


Fig. 1.

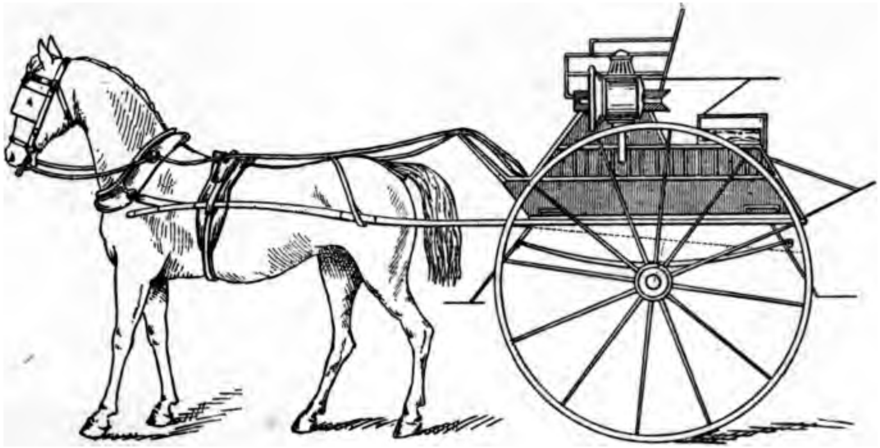


FIG. 2.

only one seat for the hind axle to bear.) This is especially the case with those short coupled carriages so widely advertised, in which the front wheels are right underneath the driving-seat.

Best Point of Draught.—In a two-wheeler it is well known that if the horse pulls, say from a point much above the axle, he is pressed downwards by the shafts, owing to the weight that has been thrown forward. If, again, he pulls from below the axle, there is a tendency to lift him (the horse) up from the ground. It therefore follows that if the horse is neither to be pressed down or lifted up, the carriage must be drawn from the centre of the wheel, or as near to it as possible, knowing that a horse cannot economically both carry and draw a weight at one and the same time.

Comparing the point of draught in a hansom with that of an ordinary dog-cart, we see (Figs. 1 and 2) that it is much superior, as the trace of the hansom is in the line joining the axle, while the trace of the dog-cart, if extended, would come above the axle, hence causing a tendency for the dog-cart to turn round the axle, and so increase the weight on the horse's back. If however this dog-cart was fitted, as is suggested further on, with a pulling-bar hung by chains from the axle, the trace would then be in the correct line.

In a four-wheeler, if the same rule holds good, we know by mechanics it will be a point between the front and hind wheels, such that the distances from it to the centres of wheels are in the inverse ratio of the forces required to pull the front and hind wheels along the road, and the power required will be equal to their sum, and in the same direction. First let us suppose that above this point is the best point to draw from; we see at once, that if drawn from here, there is a tendency for the body to turn round the front axle, thus putting more weight on the front wheels, and less on the hind. What results from this we will now consider. Let W' & W'' = weight on front and hind wheels respectively, and $W' + W' =$ weight of carriage. Suppose wheels are equal. In turning round front axle, W' & W'' will both change their values, but W, their sum, will remain unchanged as the carriage is the same, and therefore P, got by expression (IV.), will be unchanged. On looking further into the subject, it is found, however, that in this repeated transfer of the load from the hind to the fore wheels, a quantity of force is absorbed from the tractive force. The exact amount of increase, as you raise or lower the point of draught, the author has been unable to ascertain, in spite of having made a number of experiments on the same, owing to it being small, and the tractive force so variable (see table, page 4). This disadvantage also applies to the case when the wheels are unequal. When the hind wheels are the smallest there will be an advantage, and if it is sufficient to overcome the disadvantage caused by the carriage tending to tilt, there will be an advantage in this case, in pulling it from the high point of draught. Next, taking the point of draught below the point between the axles, we find, in going over the same reasoning as before, that we get exactly opposite results, and, therefore, if the front wheel is the small one, it will be best to draw from a point nearer to the front wheel than that found by the rule. The distance will be increased, of course, as the difference between the wheels is increased.

Comparing the point of draught of a brougham and a phæton, such as is shown by figs. 3 and 4, we see at once that the first-named is the best. For produce the line of trace to meet the line joining the centres of wheels, in each case it happens to be about the middle point, which, in the case of the brougham, is the right point, as the weight is nearly equally distributed, but in the park phæton this is not the case, all the load being at the back, and, therefore, the point that the carriage ought to be pulled from is nearer the hind axle. The effect of this is that the front part of the carriage has a tendency to be lifted from the ground, with the hind axle as fulcrum. But the amount of increase is small, and, consequently, difficult to detect. If we compared these two carriages for the position of load, we would decide in favour of the phæton, as the greater weight is on the higher wheel.

Height of Point of Draught.—Having proved the best point of draught for a two or four-wheeled carriage, and also the best inclination for trace (see page 10), we have disposed of the carriage, and may now turn our attention to the horse, and consider what point, and what angle it is best for him to pull from. As to the first, authorities seem to agree that it is a point about the middle of the shoulder-blade. But as to the angle, they differ. Some say horizontal,* some at right angles to the shoulder-blade,† and others at certain angles to suit the kind of road and strength of horse‡. Our idea is to follow Youatt's opinion, when he says that "as far as mere traction is concerned, there is no particular angle which will *always* produce the greatest effect, but it must depend upon the particular capability of the horse, and this, in its turn, varies, and is affected by circumstances, as to roads, &c." Very seldom you are able to get a horse that will work easiest at the same angle of trace as the carriage ought (according to page 10) to be pulled at, as it is generally so small (say 3° to 4°), but this is unavoidable,

---

* "Handy Horse Book," p 73. † "Draught and Harness," by Major Dwyer, 3rd edition, p. 218. ‡ Youatt's "Essay on Draught," in *Book of Horse*, 1874 edition, p. 543.

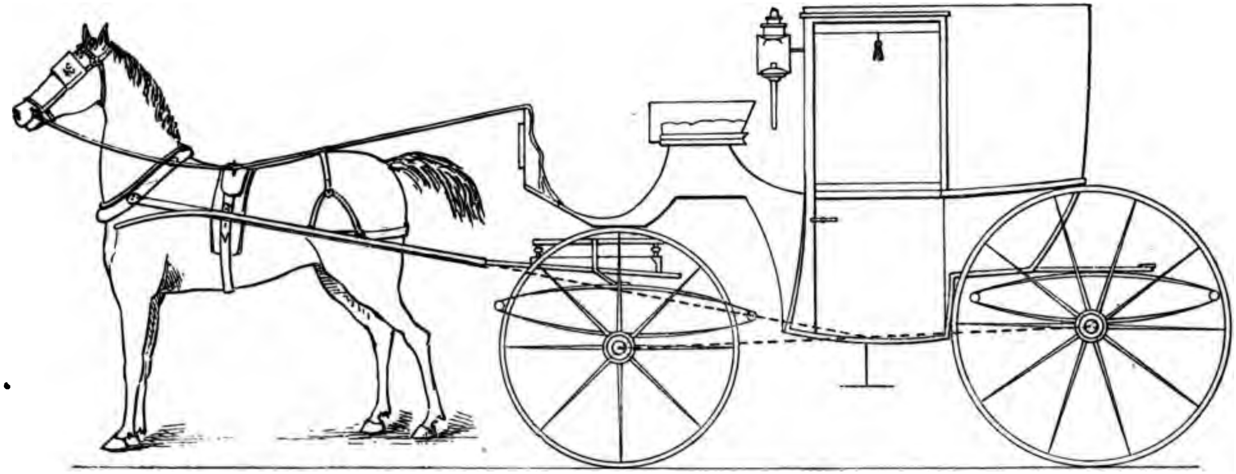


FIG .3.

UNIV. OF MICH.

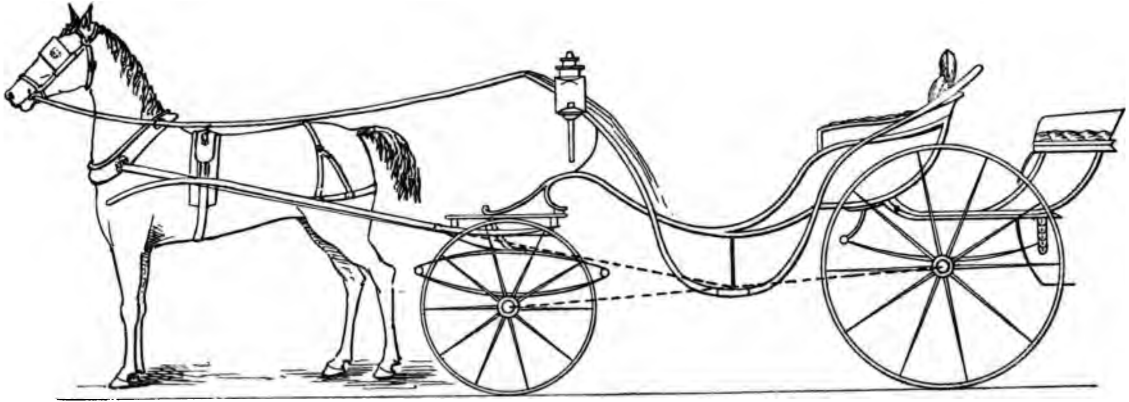


FIG. 4.

as the easy working of the horse must be considered before that of the carriage. The usual inclination of trace is a little under 15° (when the horse is in motion it is less still), and upon this the following table of heights of draught bolts is calculated, but it must be remembered that no hard and fast line can be drawn; indeed, it varies very much with the kind of carriage. Often a less inclination might be used to advantage.

Height of horse.	Height of Hame Tug.		Length of Trace.		Height of Draught Bolt.	
HANDS.	FT.	IN.	FT.	IN.	FT.	IN.
16	4	3	6	3	2	10
15	4	0	6	0	2	8
14	3	9	5	9	2	6
13	3	6	5	6	2	4
12	3	3	5	3	2	2

Comparison of Two and Four-Wheeled Carriages.—Comparing two and four-wheeled carriages for draught, we find that if the weights, size of wheels, axles, &c., are the same, that there is no difference in the draught found by expression IV. for the two cases. But in practice it is a good deal easier to make a two-wheeler lighter, and also to get larger-sized wheels than in the case of a four-wheeler, and, therefore, they are generally preferred; and if it were not for one great objection, they would be much more generally used. The objection is that in going down-hill weight is thrown on to the horse's back, and in going up-hill the reverse takes place, which is quite contrary to what is most desirable for the horse, as it is well known that if the horse has a good weight on his back in going up-hill, he has a firm grip or hold of the ground, and that in going down-hill weight ought to be removed, rather than put on, as it makes him liable to stumble. Many plans have been devised to get over the difficulty, by moving either the seat, or body, or both so as to balance the weight when on an incline; but the simplest plan, though perhaps not the smartest in appearance, is to have a cranked axle, or to put the axle through the body, so that the centre of gravity is brought below centre of wheel; then in going down-hill weight is taken off the horse's back, and in going up-hill it is thrown on to it. Of course, in a two-wheeled carriage there is the risk of the shafts breaking, and of being thrown to the ground, but if they are made of good lancewood, and hung on the fulcrum principle, without bolts through them, and the cart is well balanced, there is very little fear of this; besides, a four-wheeler is liable to overturn if the carriage is locked on the side of a hill.

The Best Method of Working Two or Four-Wheelers.—First, speaking of four-wheelers, we find that two horses with a pole work a carriage much steadier than if they were in shafts, as the pole prevents the front carriage turning from side to side when the wheels meet stones in their track, as is the case with shafts. It need scarcely be mentioned that a long pole does this more effectually than a short one. The same holds good in two-wheelers, though in a different way, as the shafts cannot play, being rigidly fixed to the body, but they are generally made so wide that they play on the horse's side, which amounts to the same thing.

The two best ways of working a pole in a two-wheeler are the curricle and Cape methods. In the first-named the weight of the pole is borne on the backs of the horses, and in the second, by their necks. The first method is the most suitable plan in respect to the weight being borne on the horses' backs, but it is found dangerous, as if one horse falls, the weight of the pole all rests on the fallen horse, and he cannot rise without assistance. The Cape method has not this disadvantage, for, as soon as the horse falls, the other horse relieves him of the weight of the pole. Another method is to pull the carriage by means of a yoke fixed to the saddles. This is seen in the Indian Tonga, but cannot be so satisfactory a plan, as the saddles will always have a tendency to slide back.

Of course, in all two-wheelers great care must be exercised in balancing, whether used with pole or shafts. If the weight is on the horse's back he does double work, and there is a liability to break the pole or shafts. The method of tandem driving is the most uneconomical method, as the leader seldom does his share of work.

Springs.—We now come to consider springs, which are added to a carriage, more especially for the comfort of those conveyed, though at the same time they may tend to lessen draught. They reduce the draught, as the shocks that a carriage sustains by knocking against obstacles are modified. A wheel on coming in contact with an obstacle rises to the top of it, and if there are no springs between the wheel and body, the sharp resistance of the obstacle to the wheel is at once conveyed to the body; but if springs are interposed, it simply compresses the springs, they then expand, and give (very nearly) the whole of the shock to the body, but as the springs will not expand all at once, the shock is given gradually to the body. It is at the same time modified, as directly the wheel has mounted the obstacle it falls, thus the body is pushed up and pulled down at the same time, and if the springs are good, no shock ought to be felt by the occupants, but only a slight oscillation, due to some unusually high obstacle on the road, or a jerk from the horse. The effect of the springs when the carriage is just on the point of motion is *nil* (there being no shocks), and when in motion is partly to counteract the increased draught due to that motion (see page 8), and, consequently, the suspension ought to be more perfect the quicker the carriage is intended to go. Springs have more effect on rough than smooth roads, as the shocks are greater. They are also more efficient when they are easy, as when they are stiff they have nearly the same effect as if the carriage was without them. It would have been well, perhaps, to have gone into the difference in ease, &c., of the various springs now in use for carriages, such as Cee, Elliptic, Morgan's, Side, Elbow, Spiral, and Volute, and to have shown how increasing the number of plates, reducing their thickness, and increasing their length, and reducing the compass made the spring easier, and also to have shown how to calculate their strength for different loads, so that a carriage might remain level, whether it was loaded or empty, but space forbids anything of the kind. We must, however, name that Cee-spring carriages are more difficult to draw than ordinary ones, not from any fault of the Springs, but owing to the swaying of the body from side to side when being driven over rough roads.

Lancewood Shafts.—In two-wheelers, when the shafts are lightly made, and properly hung, a great deal is added to the ease and steady running of a carriage.

India-Rubber Tyres, &c.—These greatly add to the comfort of a carriage, and at the same time tend to reduce the draught, acting as ordinary springs to modify shocks, but it may be mentioned that the compression of the india-rubber, as the wheel rolls along, retards the wheel to a slight extent. As doing a similar and yet different work, we may name Mulliner's india-rubber collars, also rubber cushions round the boxes within the naves of wheels, rubber cushions at the spring-eyes, and spiral springs in the cushions of carriages, and many similar inventions. These, though they do to a certain extent modify shocks, are used more for preventing vibration, which is so very unpleasant in some carriages. India-rubber, as we all know, stops vibration very effectually.

Springs in Traces.—As to the use of india-rubber, or other kind of springs, in traces, we cannot concur in the opinions advanced by many previous writers. They do not reduce draught, nor do they increase it, but they give several advantages to the horse, which enable him to do more work with less exertion. Space will not permit of a full proof of this assertion, but as the writer is strongly in favour of spring traces of some kind, especially in heavy work, he will answer two points that have been raised against them.

First. In starting, we all know that a carriage is difficult to start, but easy to pull when once started ; this is the case with all machines, and also with animals. In starting to pull a carriage with the ordinary almost inelastic traces, a horse must start both himself and the carriage at the same time ; while with springs in traces, he first starts himself, and then the carriage ; thus not getting the hard work all at once, but first one part and then the other. The amount of work (number of foot pounds) actually done in the two cases is exactly the same, the only difference being that more time is given to him in the second case. The only other case I will touch on is the case when the carriage comes to a high obstacle, and is nearly stopped. In the slackening of pace caused by coming against the obstacle, in the ordinary case both carriage and horse lose their impetus at the same time. The horse, when he finds he is pulled back by the carriage, instinctively makes an extra effort to get over the obstacle, by which time the carriage has surmounted the obstacle, and thus the carriage comes on the horse's heels, and, consequently, power is wasted. In the case with springs, the carriage is checked a little, but the horse does not feel the check (but goes straight ahead as if nothing had happened) until a little of his impetus is used in stretching the spring. Thus he only gradually becomes conscious of a greater resistance, and before he has fully extended the spring, the carriage will, by its own impetus, have surmounted the obstacle. All that will be required of the horse now will be to gradually (not with a sudden extra effort as before) restore the lost impetus to the carriage.

Pulling or Sway Bars, Swiffle, or Swingle Trees.—These, without doubt, are an advantage to the easy running of a carriage. A horse, when in motion, first pulls one trace and then the other as he works his shoulders. It therefore follows that if each trace is attached (one at each side) rigidly to a carriage there will be a tendency for the carriage to go from side to side, and not straight, whereas if the traces are attached to the ends of a bar, moveable about its centre, there will be no tendency to go sideways, as the carriage will be pulled steadily from the centre of bar, thus saving much power that would have been used in pulling the wheels sideways (not exactly straight or askew). The same argument holds good in the case of a pair of horses when a set of bars is used, with the additional advantage of getting an equal amount of work out of both horses. There are various ways of fixing the bar on a two-wheeler, but the best plan is by two chains from the axle, the bar being kept up from catching the horse's heels by two straps fixed to the front of the body. This plan has the additional advantage of getting the draught direct from the axle.

APPENDIX.

To prove formula $P = \frac{(W-w) f r}{R}$ ....(III.)

These experiments were made with wooden wheels and a wrought-iron axle. The weight was attached by a strong piece of tape over the top of wheel, running freely, half the weight being on either side. P the power, was applied by a strong thread wound partly round the wheel so as to pull at a tangent to the wheel, and its magnitude was shown by one of Salter's spring balances. To prevent any error that might arise from the weights not being exactly balanced, the mean of the back and forward results was taken. The value of $f = \cdot 17$ was obtained by comparing a large number of results together, which it is unnecessary to show here.

R = Radius of wheel..	1·5in.	1·5in.	3in.	3in.	3in.	6in.
$P = \frac{P' + P''}{2}$ got by expt.	3·3oz.	6·5oz.	6·3oz.	4·75oz.	3·1oz.	3·5oz.
P = power got by rule.	3·5 ,,	6·3 ,,	6·8 ,,	4·9 ,,	3·4 ,,	3·5 ,,
W = weight of wheels and load, or total pressure on axle......	124 ,,	224 ,,	481·7	352 ,,	242 ,,	520 ,,
f = co-efficient of friction between wood wheels & iron axles as found by other experiments	·17	·17	·17	·17	·17	·17
r = radius of axle ...	·25in.	·25in.	·25in.	·25in.	·25in.	·25in.

To prove formula $P = \frac{W A}{R} + \frac{(W-w) f r}{R}$ ....(IV.)

These and the following experiments were made with a small wagon, on four wooden wheels, and it was pulled horizontally from the middle of the front axle, on a horizontal table covered with a sheet of india-rubber, to make traction as constant as possible, P being the mean between the forces required to move wagon back or forward. The value of $A = \cdot 025$ inches for the wheels on india-rubber was obtained from a large number of experiments, which it is needless to add here.

R = radius of wheel ...	1·5in.	1·5in.	3in.	3in.	6in.	6in.
P = power at axle found by experiment.........	·46lbs.	2·4lbs.	·23lbs.	1·25lb.	·15lbs.	——
P = ditto by rule	·63 „	2·9 „	·34 „	1·46 „	·21 „	·448lb.
W = weight of wagon and load	15·5 „	67·5 „	18·0 „	69·0 „	28·5 „	49·5 „
w = weight of 4 wheels	1 „	1 „	3·5 „	3·5 „	14 „	14 „
r = radius of axle	·25in.	·25in.	·25in.	·25in.	·25in.	·25in.
A = length of arc between obstacle & road	·025 „	·025 „	·025 „	·025 „	·025 „	·025 „
f = co-efficient of friction at axle	·17 „	·17 „	·17 „	·17 „	·17 „	·17 „

To prove that changing centre of gravity of a carriage makes no difference in the draught if the wheels are equal, the apparatus, &c., the same as above :—

Height of wheels (diameter)	3in.	6in.	12in.
Weight ditto	51lbs.	53·5lbs.	103·5lbs.
Power when weight in front	2·1 „	1·4 „	·97 „
„ „ „ at back	2·1 „	1·4 „	·97 „

To prove formula $P = \frac{WA}{R} + \frac{(W-w)fr}{R}$ ......(IV.)

Or, $$P = A\left\{\frac{W'}{R'} + \frac{W''}{R''}\right\} + fr\left\{\frac{W'-w'}{R'} + \frac{W''-w''}{R''}\right\}$$

This last form of equation (IV.) is for a four-wheeled carriage, and is got from the other by supposing there are two draughts, one with the two front wheels, and one with the two hind wheels. The different values of W, R, &c., being distinguished by a single dash for the front, and a double dash for the hind wheels. In this way you get P' for front, and P'' for hind wheels, and adding these together you get P, the total draught of the carriage, equal to the above expression. Of course if the front and hind wheels are equal, this expression returns to its old form.